TAIWAN SEMICONDUCTOR MANUFACTURING COMPANY: 
THE SEMICONDUCTOR SERVICES COMPANY

The main thing that we've learned is that foundry is a service-oriented business, so we are molding ourselves into a service company.

—Morris Chang, Chairman and CEO, TSMC

Founded in 1987, Taiwan Semiconductor Manufacturing Company (TSMC) was the world’s first pure foundry, focused solely on the manufacturing of semiconductors. Operating in the cyclical semiconductor market, the company managed to grow rapidly and to become the world’s 8th largest semiconductor manufacturer with more than 50 percent market share in the foundry business. In the company’s early days, TSMC management focused on manufacturing excellence and technology leadership. As competition in the sector intensified in the late 1990s, the company began to focus on customer service to further differentiate itself from companies like UMC, its next door neighbor and closest competitor, and the rapidly growing Chinese foundries.

The company invested heavily in the development of innovative, value-added services and proprietary information systems that would facilitate better communication and improve customer service, putting in place eCommerce applications such as eFoundry and Enterprise Supply Chain Management suites. TSMC management believed that customers, typically U.S. based integrated circuit (IC) design houses facing high financial stakes, rapid technological innovations, short product life cycles, and intensive competition, would choose a foundry business partner based on quality, trustworthiness, and reputation, as opposed to price only.

Could superior customer service make an impact in a capital intensive, process- and quality-oriented industry such as the semiconductor industry, or would TSMC have to compete on price? Company executives believed that TSMC’s increase in market share during the 2001 industry downturn was evidence of the effectiveness of their strategy.


Shiri Shneorson prepared this case under the supervision of Professors Hau Lee and Seungjin Whang as the basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation.
THE SEMICONDUCTOR INDUSTRY - BACKGROUND

The semiconductor industry was born in the 1950s when the first integrated circuit (often called a chip) was developed by Jack Kilby of Texas Instruments and Robert Noyce of Fairchild Semiconductors (who later became Intel’s co-founder). In the early days, its main use was in mainframe computers, but in the past decades ICs had become key components for computing, communications, automotive, industrial, consumer electronics, and military applications. In its four decades of existence, while intensely cyclical, the semiconductor industry had grown at an average rate of 14.9 percent per year. Periods of rapid growth were followed by periods of low demand. Consequently, the industry had drastically fluctuating levels of capital investment with repeated patterns of over- and under-expansion (Exhibits 1 and 2).

The Making of a Chip: From Design to Manufacturing

There are three major steps in making a chip: design, fabrication, and assembly, and test. At the design stage, engineers translate a set of specifications regarding the required device functionality into a detailed description of a physical silicon chip that can be manufactured reliably. It is a task that requires a high level of expertise, as a single chip may consist of tens of millions of transistors placed in several layers and connected with wires that are less than a micron wide, all coordinated to handle thousands of instructions per second.2 Once the design phase is complete—a milestone called tapeout—a file (historically stored on a tape) containing the detailed design is transferred to the manufacturing organization.

A semiconductor chip is the most complex manufactured product on earth and it takes hundreds of steps in the world’s cleanest environments to make a chip. This manufacturing process is known as wafer fabrication, and consequently the manufacturing facilities are called fabs, or foundries. The silicon chips are manufactured on circular silicon wafers 150, 200 or 300 mm in diameter and less than 1 mm thick. Each wafer yields many dice, rectangular single silicon chips which are usually on the order of a centimeter square. Each die contains hundreds of millions transistors—tiny switches that turn a current on and off within the chip. The transistors are made in a sequence of about six hundred repeated steps that include doping certain regions of the wafer by implanting ions that change the electrical characteristics of the semiconductor material, heating the wafer to a temperature of several hundred degrees Celsius to redistribute the ions and produce an isolating film on top of the wafer, and depositing materials on top of the wafer. The transistors are formed on the surface of the wafer while the wiring connecting the transistor is built on its top. It takes about eight weeks to complete the production of a silicon wafer.

At the assembly and test stage, the chips are tested while still on the wafer, and the wafer is then cut into dice. More thorough testing is performed on each die to study its exact performance characteristics (which may vary from wafer to wafer or even from die to die due to variations in the production process), and then the chip is packaged, assembled on a board if required, and ready to be shipped.

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2 A micron is 10^-6 meters.
Building a Fab

The cost of building a fab roughly doubled every two generations of new technology, rising from approximately $250 million in 1983 to about $3.6 billion in 2003 (see Exhibit 3). Most of that cost, roughly 70 to 80 percent, was the cost of equipment, which had to be updated or replaced as new technologies emerged. Typically, fabs took eighteen months to design and construct and six to twelve months or more to ramp up production to full scale.

IC Industry Structure and Supply Chain

In the beginning, all IC manufacturers in the semiconductor industry were Integrated Device Manufacturers (IDMs)—fully integrated manufacturers that designed, fabricated, and marketed their own products and, in some cases, even built their own production equipment. However, by the mid-1970s, many had given up manufacturing their own equipment and later started outsourcing other low profit activities such as assembly and testing. IDMs included both systems companies such as IBM, Hitachi, Lucent, and Ericsson, and chip companies such as Microchip, Atmel, and Macronix. Intel was the world’s largest chip manufacturer. In 2003, Intel’s semiconductors sales were almost three times the size of Samsung’s, the number two ranked company. In fact, Intel represented more than a quarter of the total top ten semiconductor companies’ sales in 2003 (see Exhibit 4).

Historically, IDMs resisted outsourcing their own chip production, because fabs were viewed as providing leverage in acquiring ideas for new chip designs. However, following the steep decline in memory chip prices in the mid-1980s, many IDMs, particularly those in high cost North America, found it was no longer profitable to build fabs to manufacture their own memory chips. They started to gradually outsource their production to more efficient manufacturers: IDMs such as Toshiba in Japan or Samsung in Korea. These IDMs filled underutilized fab capacity with other IDM’s chip production, becoming the first contract manufacturers. By 1999, most of the leading IDMs outsourced some significant part of their production, and IDMs were projected to outsource about 20 percent of their total production by 2008.

In the late 1980s, entrepreneurs with new ideas for chip designs realized that they could use Japan’s, and later Korea’s, fabs to manufacture their chips on a contract basis. Since they did not own or operate fabs, these chip companies became known as fabless organizations. Fabless firms generally had high profit margins and strong free cash flows, reflecting the relative lack of capital intensity in their business model. Fabless manufacturers could also concentrate their limited engineering resources on innovating new designs rather than on solving manufacturing issues. The business model’s disadvantages were that the IDMs offering contract manufacturing services sought to capture most of the value arising from the sale of the chip either through licensing or revenue sharing, and typically left room for improvement regarding customer

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3 A generation is defined by the width of circuitry, so that the move from 0.23 micron to 0.18 micron is a generation. The width of circuitry refers to the smallest size of the transistors on the IC. The feature size is a defining aspect of advanced IC, because smaller features result in better IC performance and lower costs.

4 Systems combined numerous electronic components together, including semiconductor chips, to achieve a particular functionality.

5 “Taiwan Semiconductor Manufacturing Company”, HBS N9-700-090.
service. They were also generally less interested in doing the contract work during chip industry cyclical peaks (such as 1983, 1988, 1995, and 2000) when they wanted to devote more of their scarce capacity to their own products. In 1987, Taiwan Semiconductor Manufacturing Company was founded. TSMC was the first “pure” foundry in the world: a premium chip manufacturer with no products of its own. The contract manufacturing model proved successful and was quickly imitated by many others. By 2004, pure foundries had a 23 percent share of the total chip manufacturing market, earning $4.4 billion in the third quarter of 2004 (see Exhibit 5). The market share of pure foundries grew 20 percent in 2002, 32 percent in 2003, and had an estimated growth of 52 percent in 2004 (see Exhibit 6). Leading analysts, such as Gartner/Dataquest, predicted that foundries would account for as much as half of the total wafer production by 2010.

Shifts in the industry’s structure over the course of 20 years also affected the structure of the industry’s supply chain, transforming it from being centrally coordinated and fully owned by the IDM, to being a vertically disintegrated supply chain, with different expert players performing the different roles (see Exhibit 7).

THE BIRTH OF TAIWAN’S SEMICONDUCTOR INDUSTRY

Taiwanese economy in the 1950s was focused on production of commodities. In the 1960s, it was dominated by exporting for light industries. Research and development activities were rare in both the industrial and academic communities. In the late 1950s, the Taiwanese government recognized that the country’s economic future would be limited by the island’s scarce natural resources and small domestic market and decided that a logical course was to develop technology-intensive industries in general, and an IC industry in particular. In 1958 the government established the National Chiao Tung University (NCTU) in Hsinchu. NCTU had only one institute, the Institute of Electronics. Early in the 1960s, NCTU began research on producing semiconductors and established the nation’s first semiconductor lab. Consequently, teaching and research on semiconductors became the focus at NCTU, up-to-date laboratories were built, and professors from worldwide leading institutions were invited to engage in teaching and research.

In 1973 Taiwan’s government established the Industrial Technology Research Institute (ITRI). ITRI’s mission was to rapidly diffuse technology into the private sector. It imported new technology and transferred it to the private sector on a non-exclusive basis. In 1974, the Electronics Research Service Organization (ERSO), a specialist semiconductors and electronics laboratory was formed within ITRI, and was charged with seeding a semiconductor industry. One of ERSO’s accomplishments was the construction of an IC manufacturing factory for experiment and research in 1976, in collaboration with RCA.

The government realized that in addition to technology, developing high-tech industries required investors and a place to breed new technologies and ventures. Attempting to emulate the success of the Silicon Valley, a science-based industrial park was chosen as an effective instrument for development: it supplied a locus around which technological development could cluster. In the

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6 For further information, see “Taiwan Semiconductor Manufacturing Company”, HBS N9-700-090.
late 1970s the Hsinchu Science-based Industrial Park (HSIP) was established adjacent to NCTU, the National Tsing Hua University (the top university of science and technology in Taiwan), and ITRI. In addition to the park, the government set up housing, medical services, and schools in the area.

The 1980s saw the founding of several IC design houses, such as Weltrend, and manufacturing facilities, such as UMC, in HSIP. By the end of the 1980s, Taiwan had gained a foothold in almost every segment of the chip market and in every level of the semiconductor supply chain. During the 1990s, Taiwan’s IC design and manufacturing supply network was composed of more than 150 related IC companies (see Exhibit 8). The workforce exceeded 50,000 employees, most of whom were college graduates and bi-lingual. The total output value of Taiwan’s IC industries in design, fabrication, and packaging in 1999 was over $15.4 billion, and about 15 percent of the world’s capital investment in IC production capacity was in Taiwan, ranking it the third in the world, next to the United States and Japan.\footnote{Chun-Yen Chang and Po-Lung Yu, \textit{Made by Taiwan. Booming in the Information Technology Era} (World Scientific, 2001).}

**TAIWAN SEMICONDUCTOR MANUFACTURING COMPANY (TSMC)**

**Founding TSMC**

In 1985, Morris Chang, chief operating officer of the General Instrument Corporation, a former vice president of Texas Instruments (TI), and a 30-year veteran of the U.S. semiconductor industry, was appointed president of ITRI. He was asked by the Taiwanese government to establish an internationally competitive semiconductor manufacturing company. At the same time (1983 through 1988), ITRI was implementing a large VLSI (Very Large-Scale Integrated) circuit research project, with the aim of establishing advanced semiconductor fabrication technology in order to support the emerging fabless IC design houses in Taiwan. This project, in 1985, had successfully developed 2um (micrometer) resolution technology for manufacturing IC in a pilot plant (commercial state-of-the-art technology at that time was 1um).

Chang formulated three strategies for creating the new company. The first, and most innovative, was that the company should be a dedicated IC foundry with no products of its own, set up to serve the growing number of fabless design houses, which at the time contracted their manufacturing to Japanese chipmakers under unfavorable terms. He based the idea on the observation that Japanese chipmakers consistently managed to achieve higher yields than their American counterparts. Chang believed that this was due to the Japanese work ethic, better technological training, and low employee turnover, qualities that Taiwan shared.

The second was to form a joint venture with an internationally competitive semiconductor company in order to be assured of substantial orders from the venture partner and acquire advanced manufacturing technology. Chang contacted more than ten internationally known semiconductor companies, but most showed no interest. In the end, Philips, the largest semiconductor company in Europe, participated in the joint venture.
The third strategy was to transfer resources involved in the VLSI project, including engineers, equipment, process technology, building, and land, to the new entity to speed up the company’s establishment.

In 1987, TSMC was formally founded in HSIP as a joint venture among the Taiwanese government, Philips, and other private investors. An immediate success, TSMC maintained a highly regarded record in revenue and income (see Exhibit 9), became the world’s largest foundry (holding approximately 50 percent of total foundry market share between the years 2002 and 2004, about twice that of its closest competitor), and the world’s 8th largest semiconductor manufacturer in terms of sales (see Exhibits 4 and 6).

**The Company’s Growth**

Change described TSMC’s vision this way:

> Our vision is to be the most advanced, innovative and largest provider of foundry services, and in partnership with our customers, forge a most powerful force in the semiconductor industry. To realize our vision, we must be:

- (1) A technology leader, competitive with industry leaders
- (2) The manufacturing leader
- (3) The most reputable and service-oriented; and the greatest total benefits provider.

TSMC’s development followed these three principles.

In the company’s early days, development was concentrated around achieving operational excellence and manufacturing leadership, measured in high capacity utilization, low costs, and high and reliable yields. The company employed a continuous improvement method with the goal of reaching yields as close to 100 percent as possible. Failure analysis revealed that delayed periodic maintenance was the most frequent reason for equipment failure. To reduce equipment failure, TSMC installed a sophisticated computer system to monitor and study tools up-time. The company used the knowledge gained to automate periodic maintenance on the tools. Also, engineers from the different fabs were given time to share their best practices, and work together to improve the company’s operational performance. To enhance scale efficiencies, TSMC used a deliberate strategy, known as *clustering*, locating five (later six) fabrication facilities at the HSIP, all close together. Co-location provided TSMC with the ability to share resources and use machinery efficiently across fabs. For example, temporary backup problems and bottlenecks in one plant could be absorbed by another. Although this strategy posed certain risks, making the company highly vulnerable to incidents such as water shortage or earthquakes in the region, it was instrumental in helping TSMC reach high levels of capacity utilizations, higher than 100 percent of the installed base at times.

Typically, fab operations required about 1,000 employees, with roughly 300 engineers (equipment and process engineers) and 700 operators. TSMC had more engineers on the plant

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8 Source: TSMC.
floor than the standard. They used their expertise to find clever ways to prolong the life of expensive equipment, and to figure out ways to use older capacity to produce some of the less advanced technology products—a significant cash cow. Also, they managed to refine the skill of introducing products to the factory at the right time in order to optimize the products’ flow.

TSMC relied heavily on locally trained engineers, but many senior managers had advanced degrees from U.S. universities. Employee turnover was among the lowest of the local industries. Even though base salaries were lower than U.S. engineering compensation, profit sharing at the end of each year in the form of stock grants (issued at their par value) and performance-based bonuses made compensation at TSMC competitive, reaching as high as $500,000 in good years. This form of compensation also aligned employees’ incentives with the company’s, encouraging employees to work hard, meet their goals, and apply peer pressure, when necessary, to resolve issues.

In the 1990s, TSMC’s second developmental phase, the company concentrated on technology development. The company’s goal was to be the industry technology leader, just as Intel was the leader in the CPU business and Samsung in the memory business. To gain and retain technology leadership, TSMC invested heavily in R&D (see Exhibit 10). For example, TI’s R&D budget was about the same size as TSMC’s, though TI was an IDM that applied its R&D budget to new products development as well as to the development of the fabrication process.

By 1995, TSMC developed 0.5-micron technology, thereby closing the technology gap between itself and almost all IDMs. It was at that point that business started coming in more rapidly. By 2000, they had closed the gap with all of the world’s manufacturers, including Intel (see Exhibit 11). By 2004, the company was a technology leader among the dedicated foundries in terms of net sales of advanced semiconductors with a resolution of 0.18-micron and below, and one of the leaders in the semiconductor industry in general. The company also made a series of important technological innovations. For example, TSMC was the first to produce a fully functional SRAM chip using 90-nanometer CMOST process technology in March 2002, one year ahead of the International Technology Roadmap for Semiconductors. The company was the first foundry to offer 90nm low-k production in 2003 in its then newly opened, state of the art 300mm fab in HSIP, and was making significant progress in advancing the 0.13-micron process development and making it available to its customers on a large scale.

Since 1997, TSMC had been focusing on a new phase of competitiveness and growth—customer service and partnership, and has managed, yet again, to innovate the foundry business.

THE NEXT PHASE OF GROWTH: CUSTOMER SERVICE AND PARTNERSHIP

TSMC management philosophy with respect to customer relationships, as put by Kenneth Kin, Senior Vice President of Worldwide Marketing and Sales was as follows:

The best customer relationship for TSMC occurs when a customer views TSMC as a partner. TSMC’s three tests of partnership are (1) the customer gives TSMC the first look when they have a foundry opportunity, (2) TSMC will get the last look before going somewhere else, and (3) they share their product roadmap with TSMC. The worst case is when a customer uses TSMC as a commodity provider
and shops around for the lowest price. In the long term, this is the worst option for the customer.\(^9\)

To achieve this partnership goal, and thus to differentiate itself from its competitors and be able to command premier prices (typical TSMC prices were 10 to 30 percent above its competition), TSMC focused on the following dimensions of customer service: Providing high quality products while meeting customer deadlines, providing customers access to the most advanced technology, having market intelligence to avoid being blind-sided by customers, giving maximum capacity flexibility to customers, and building customer confidence in doing business with TSMC. To TSMC, customer service meant:

- **Care.** What the customer cared about was what TSMC cared about and measured, as reflected in its emphasis on delivery schedule (rather than production schedule) and customer performance indices (rather than TSMC’s).
- **Communication.** TSMC attempted to address the customer’s culture and special needs. The company worked closely with the customer throughout the design process, helping the customer optimize the design according to the company’s manufacturing process. TSMC never held customers liable for demand mis-forecasts and offered its customers IT services and customer support to make communications easier.
- **Meeting Commitments.** The company put an emphasis on quick production ramp-up, continuous yield improvement, accuracy, and meeting deadlines.

Any special issues in the ongoing relationship with customers were communicated to all stakeholders, and a commitment date for a resolution was set. The company held quarterly reviews with all customers, and conducted an annual customer survey on key TSMC performance indicators. The survey results were compared to previous years’ results as well as to competitors’, and were closely watched by Chang himself. An annual Outstanding Customer Service Award was given to teams of employees that were recognized by customers for “going an extra mile.”

The main challenges TSMC faced in providing high quality service were: investing in the right technology and capacity, keeping cycle times low, and offering customers capacity flexibility. Some extremists in the manufacturing world believed that customers should be held responsible for the cost of changing orders and should be “disciplined” in order to prevent unnecessary stress and nervousness in the production system. For example, they argued that orders should be “frozen” at a certain point in time beyond which no modifications could be accepted. TSMC, however, embraced the opposite extreme. It attempted to offer its customers maximum flexibility even when it came at a high cost. They defined flexibility in the following ways:

- The degree to which volume changes by the customer were allowed.
- The flexibility to change the process recipe for wafer fabrication by the customers.
- The flexibility to change ship dates by the customers.
- The degree to which customers could make real time changes in production requirements.
- The flexibility to hold or cancel a job in process.

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The scale of TSMC and the company’s clustering strategy enabled the company to provide its customers with unusually high levels of flexibility. However, the cost of providing this flexibility was also high. When senior TSMC executives were asked why the company took on such an advanced approach with respect to flexibility, they all had one answer, “because we are a service company.” Although the contribution of customer service to its financial performance could not be measured directly, company executives believed it was the main reason that during the 2001 industry downturn, TSMC managed to increase its market share, and was the only profitable foundry among the top ten. TSMC executives argued that the high quality of service offered by the company made businesses that were turned down by TSMC during up-cycles (due to capacity constraints), return to TSMC when capacity constraints were relaxed.

Taking customer service a step further, TSMC developed a set of value-added services it offered its customers (see below). Their direct contribution to the revenues was small, as roughly 90 percent of total revenues were from wafer manufacturing services, and 8 percent were from mask-making.10 However, the company viewed them as an important tool to win and retain customers.

**Value-Added Services**

TSMC’s value-added services were meant to complement the company’s traditional manufacturing services. It wanted customer to view TSMC as “their virtual fab, only better.” It offered services to support both the customers’ front- and back-end operations, where front-end referred to pre-fabrication activities, such as design and mask preparation, and back-end referred to post-fabrication activities, such as assembly, packaging and testing.

As part of its front-end services, TSMC typically engaged a customer early in the design phase. By working closely with the customer during that phase (which could be six months or longer), TSMC engineers helped the customer optimize the design to run efficiently in its fabs. This service improved TSMC’s knowledge of the customer, but also made it harder for the customer to have the chip manufactured by any other foundry, as it was optimized for the TSMC manufacturing process. TSMC engineers prided themselves on helping customers achieve better performance chip designs that could ultimately draw higher prices in the market. Also, TSMC worked with Electronic Design Automation (EDA) companies who made the software tools used by the design engineers, to ensure that their tools produced designs that could be manufactured by TSMC.

Other value added services included the following:

**Library and IP Development**

The use of third party libraries in the design of a chip became a common practice as technology advanced rapidly, and every technology generation required a new set of libraries.11 On top of

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10 Masks are high-purity quartz or glass plates that contain precision images of the integrated circuit, and are used by the chipmaker to optically transfer images onto the silicon wafer. They are a key element in the manufacturing process.

11 Libraries are a popular way to package code for reuse.
saving time, third party libraries were typically bug-free and fully characterized. TSMC paid library providers to develop specialized libraries for the company, and offered them to its customers. Also, TSMC had an internal design team that created designs for internal use (mostly application-specific integrated circuits (ASICS) designs\textsuperscript{12}). This team also experimented, for a short period of time, with licensing these internal designs to its customers. However, since these libraries were not intended for usage in a wide range of products, many customer complaints arose and TSMC phased out distributing its own libraries. As of 2004, TSMC maintained its internal set of libraries for three purposes: To maintain expertise in-house, to avoid too much dependence on third party providers, and to improve its bargaining position with these third party library suppliers. The company took pride in having developed an integrated "Design Flow-Integrated Library Value Chain" with a single goal in mind: Provide the shortest time to tapeout and to volume production. The library portfolio included comprehensive process-specific libraries, the foundry industry's only documented evaluation process, and a network of third party library vendor relationships that promoted direct access to technical services and early access to leading-edge process specific technologies. The TSMC libraries were used by about 15 percent of its customers.

As the geometry of chip making continued to shrink and ever larger chips were possible, it became a common practice to combine chips with several functions into one chip (known as system-on-a-chip, or SOC). However, few companies had the expertise to design all the intellectual property (IP) needed for a true SOC, and few had enough engineering resources to complete such a massive project. Even those with the required knowledge and plentiful resources might still be unable to finish a complete chip design in time to meet accelerated market demands. As a result, a merchant semiconductor IP industry had arisen to provide designs that were developed specifically for reuse in a wide range of applications. These designs were backed by documentation and support and were offered for license as a product.

TSMC stayed out of the IP market, as it viewed it as a turbulent market, but initiated a verification program for third party IP cores. It agreed to validate on silicon IP cores for suppliers (that is, to actually produce the core in its fabs in order to check its quality and manufacturability), as long as a TSMC customer was using that IP. It was costly to validate IPs, but TSMC opted to bear the cost to ensure that its customers had a wide variety of quality IP cores to choose from and to secure manufacturability at TSMC. TSMC put the IPs on its website alongside its three-star rating system. The first star was a result of a simple TSMC review, the second came from silicon validation, and the third star arose from use in a customer production. The customers negotiated directly with the IP vendor on the licensing terms. About 75 percent of TSMC customers used the company’s validates IPs in their designs in 2004.

\textit{Cyber-Shuttle}\textsuperscript{SM}

An important component in the semiconductor manufacturing process is the photomask, or simply, the mask. A mask contains precision images of the integrated circuit, and is used as a “master” by the chipmaker to optically transfer images onto semiconductor wafers, much like the negatives in photo development. Since the dice on the wafer are manufactured layer by layer, each requiring a unique mask, up to forty masks might be needed in order to manufacture a single chip. TSMC manufactured its clients’ masks and owned one of the world’s largest mask

\textsuperscript{12} ASICs are chips that are designed for a single application or product line.
making facilities. Traditionally, customers ordered the set of masks in the prototyping stage in order to verify a design before starting volume production, and though masks were expensive to make, they had to be remade with every design revision. As a result, customers’ nonrecurring engineering (NRE) expenses were typically high, ranging from $10,000 for a simple technology to $1 million dollars for the latest technology. To help reduce customer costs, TSMC came up with the concept of multiple modules wafers, where multiple customers could share the same set of masks (and the wafer would be set up so that it could be split to be used by multiple customers). This enabled customers to debug and refine their designs without having to invest in the whole set of masks with each iteration. Customers simply had to log into the TSMC website, get information about the next shuttle (mask in production) schedule, and book mask area on the next available shuttle for their design. Since its launch in 1998, CyberShuttle™ had provided over 400 shuttles for more than 3,000 devices and had proven cost-effective for both prototyping and IP cores validation, leading to a ten-fold improvement in ramp-up cost reduction.

**Multi-Layer Mask**

Another service that TSMC was developing to help customers reduce their NRE expenses was the Multi-Layer Mask (MLM). Using MLM, a single mask could be used for the fabrication of several chip layers all at once, each on a different area of the wafer. These different areas could then be cut and put on top of each other to make the final chip. MLM was offered only at the prototyping stage, and led to a significant reduction in the number of masks needed per product.

**Super-Hot Lot Service and Cycle Time Reduction**

The wafer fabrication process cycle times were long. Typical cycle time was 6 to 8 weeks, while it could take up to three months for the latest technology. TSMC created a special service for customers demanding an extra fast cycle time, which was often the case in the chip verification stage. The *super-hot lot* was a lot of wafers that was given special treatment and priority, achieving a cycle time that was as short as 0.8 day per mask layer. Since every such super-hot lot required special handling and set-up in the production line, it came at the expense of other lots. TSMC estimated that for every super-hot lot accepted, it lost about three to four regular production lot capacity. Still, TSMC offered the service to address customers’ special needs, and in some cases even waived the additional costs incurred. TSMC also developed a way to perform mask production and wafer fabrication in parallel. This way it could offer its customers a reduced cycle from tapeout to a prototype silicon chip.

**INFORMATION SYSTEMS AT TSMC**

In the mid 1990s, TSCM was using an Enterprise Resource Planning (ERP) system, based on SAP, to handle its finances, order management, and account tracking. It also had a computer-integrated manufacturing suite that included a manufacturing planning system (MPS), a manufacturing execution system (MES) based on Adexa, and a fab operations support system for all of TSMC’s fabs. However, TSMC management realized that information systems could be used to improve customer service and TSMC’s overall value proposition.

With the disintegration of the electronics supply chain, efficient information flow became essential for coordination between companies participating along the activity chain. TSMC aimed at building a supply chain that reduced time to market and improved profitability for the company and its partners through elaborate information technologies and collaborative business
processes. TSMC created two web-based solutions that significantly impacted the business: the eFoundry and the Enterprise Supply Chain Management system (see Exhibit 12).

**eFoundry**

In the late 1990s, TSMC built a virtual fab called eFoundry, which was a collection of Internet-based programs that allowed customers and TSMC to cooperate in design, logistics, and engineering. The virtual fab allowed customers to come as close to an in-house fab as possible. eFoundry consisted of several different programs that provided various solutions.

- **TSMC Online** – The largest portal in the industry, TSMC Online offered customers the ability to conduct transactions online and to access information regarding the full foundry life cycle through the web. Customers were able to submit purchase orders, view status of products, orders and shipments, create customer design documents, learn about TSMC foundry services, and access and control their proprietary information via this portal. TSMC was the first to provide its customers with work in progress (WIP) updates three times a day through the web, which gave customers the flexibility to request wafer holds due to quality issues or any other change in business needs. This feature was important to customers, and most other foundries quickly followed, providing WIP reports to their customers on a daily basis. TSMC online was used by over 90 percent of TSMC customers.

- **TSMC Direct** – The TSMC Direct system enabled system-to-system integration of TSMC and its customers in order to link business processes. TSMC Direct facilitated collaborative planning, tracking of WIP, and engineering data sharing. Customers connected to TSMC Direct could directly connect to TSMC’s ERP system. Some of the main advantages TSMC Direct offered were reduction in customers’ inventory levels, costs and order processing cycle times, timely information exchange, and real-time visibility into the entire supply chain. The system-to-system link was provided by a software company called Extricity. At the beginning, TSMC had to require customers who wanted to get on TSMC Direct to purchase the Extricity software. However, with the advances in the RosettaNet standards, Extricity was no longer a basic requirement. Customers who had TSMC Direct relied on it. For example, one large TSMC customer had about eighty TSMC Direct users, and they collectively logged into the system about 30 to 50 times a day. TSMC also used the same technology to connect to its back-end partners such as packaging and testing subcontractors. Using a web-based link, TSMC received confirmations, WIP status and other updates from its suppliers, which it immediately transferred to its customers.

- **TSMC-YES** – Using TSMC-YES (Yield Enhancing Solution), customers could perform yield analysis from anywhere in the world. It enabled customers to detect early low yield

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13 RosettaNet was a non-profit consortium whose mission was to facilitate collaborative development of e-business standards, based on the use of common processes and language. Companies that used RosettaNet standards could easily communicate electronically and automatically over the Internet, using a common language. TSMC was a chartered member of the Semiconductor Manufacturer Board of RosettaNet.
patterns, facilitated fast ramp-up in the introduction of new products, and enhanced the communication between customers and TSMC through the use of consistent tools.

- **TSMC-Internet Layout Viewer** – This tool enabled TSMC and its customers to view the design layout in real time through the Internet. Using this tool, various designers interacted simultaneously from anywhere in the world, making communication easier, faster, and less expensive.

- **TSM-JobView** – TSM-JobView was a tool designed to facilitate collaboration in post tapeout data inspection. It managed to reduce the mask data review cycle time from days to hours.

**Enterprise Supply Chain Management (ESCM)**

In 2000, Quincy Lin, then CIO of TSMC, saw the need for better integration of the company’s various planning processes. At the time, demand forecasting and manufacturing planning were done independently of capacity planning, and without taking into account capacity constraints. Since wafer fabrication was a capacity-intensive industry, capacity planning was central to the entire planning process. Also, at the time, capacity allocation was done in a decentralized manner, and only final coordination was done in a central, company wide manner. This created visibility issues in the organization and limited the management’s ability to evaluate capacity utilization and to track orders status closely. As a result the ESCM project was initiated in 2001 with the goal of integrating the various isolated planning functions in the organization.

ESCM focused on three key business processes: The support of customer demand, either new orders or changes to existing ones; the ability to rapidly confirm customer orders; and the ability to predict, and hence commit, to an accurate delivery date. The latter was especially critical since customers often planned their assembly, test, and marketing activities around the committed delivery date. ESCM went live in 2003, followed by the introduction of an enhanced version in 2004. It consisted of seven interconnected modules each performing one or a part of the following functionalities (see **Exhibit 13**).

- **Demand Planning** – Customers shared with TSMC their 6 to 9 months demand forecasts using the eFoundry interface. Typically, customers tended to inflate their forecasts in order to guarantee themselves sufficient capacity. TSMC, therefore, performed its own forecasting, taking into account the customer forecasts, but also performing its own segment analysis of demand trends in each industry. For example, in the graphics chip market, TSMC studied how many PCs had been shipped and how many graphic chips would likely be needed at each connect rate. Then, TSMC made a revised projection, which was considered to be more accurate. TSMC gave customers a capacity plan as feedback, though there was no commitment by either party at this stage. Account managers in each region managed this process.

- **Allocation and Capacity Planning** – The revised demand forecasts were entered to the allocation planning module, managed by TSMC headquarters. This module, together with the capacity planning module (based on i2), solved a complex linear program that
aimed to maximize service levels by allocating capacity over time. Service level could be defined in various ways, for example, minimum overall lateness or maximum output. This procedure was repeated every month, and its output, called Capacity Allocation Supported Demand (CASD), determined the demand allocation between the fabs.

- **Allocation Management, Available To Promise (ATP), and Output Planning** – Given the monthly CASD, an allocation management module produced a daily allocation plan, which dictated how the orders should be processed and executed at the fab level. On a weekly basis, ATPs were generated. The generation of ATPs required an analysis of data from the capacity plans (from the monthly capacity plan) and the actual physical fab operations (from MPS and MES). The actual work involved in planning daily wafer starts, WIP tracking, and fulfillment planning was done in the output planning module. This module assigned jobs to their slots in each fab. Its output was the Master Production Schedule.

- **Order Management** – This module handled the interactions between a customer and ESCM through the interface offered by eFoundry. Using eFoundry, customers could directly enter purchase orders, modify their orders, check the status of an order, and check the delivery date. Once wafer starts were initiated in the fabrication process, the only change a customer could perform was to request a production hold. On rare occasions, the customer could request to cancel a wafer lot. Providing the most up-to-date estimates of the delivery date required extensive processing of ESCM data, since each product manufacturing flow required many steps, at various machines, each operating under varying loads.

The enhanced ESCM system launched in late 2004, and several improvements were noticeable soon after. The confirmed line item rates (before the commit dates) were as high as 90 to 95 percent, and commit dates were more accurate. Also, the daily output planning module helped reduce excess inventory, since the reliable, timely information on scraps and yields provided a more precise way to plan new wafer starts.

**2004 COMPANY SNAPSHOT**

TSMC, with Chang acting as Chairman and CEO, had over 19,000 employees by the end of 2004. Between 1999 and 2004, the company had more than doubled its size. It had 11 operating fabs, 6 in HSIP (as well as the corporate headquarters), 2 in Tainan, Taiwan, 1 in the U.S., 1 in Singapore (as a joint venture with Philips) and 1 in Shanghai, China, giving it a capacity of almost 475,000 wafers per month. It was by far the largest foundry in the world, with revenues of $4.7 billion in 2002 and $5.9 billion in 2003. In terms of revenue market share during the same years, TSMC held 56 percent and 53 percent respectively (see Exhibit 6).

The company’s expected growth rate in 2004 was 37 percent, somewhat above the average 33 percent CAGR for the years ranging from 1992 to 2003 (see Exhibit 14). The company’s target customers, who accounted for approximately 70 percent of its sales, were fabless design houses that relied on TSMC in both up and down industry cycles. IDMs accounted for the remaining 30 percent of sales. The company’s major markets were North America, which comprised 75 percent of sales, followed by Asia with 11 percent, and Japan and Europe with 7 percent each.
In addition to being one of the industry’s largest investors in R&D, about 70 percent of the company’s marketing efforts were devoted to technology forecasting and visioning. Marketing forecasts and visions helped determine TSMC’s capacity investment and technology adoption decisions, and were routinely done for a ten-year horizon. It was the marketing findings that determined R&D direction. In fact, more than half of the company’s marketing staff had PhDs, since the role required deep knowledge of technology. An integral part of the marketing activity was the characterization of the company’s desired product mix, based on both short- and long-term goals. That is, it was important for TSMC to be the leading manufacturer of the top selling products in the market, but it was also important for the company to make sure that it was best positioned to serve emerging markets. TSMC’s target industries as of 2004 were computers, communications, and consumer electronics which accounted for 31, 42 and 20 percent of sales, respectively. Within each industry segment, the company defined sub-segments on which the company focused (for example, graphics, chipsets, and LCD controllers in computers; wireless LAN and Ethernet in communications; and game consoles and DVDs in consumer electronics). One of the emerging markets, as envisioned by TSMC’s marketing was the RFID market.\(^{14}\)

TSMC’s marketing group organized periodical Technology Symposia to introduce customers to the latest technologies and services the company offered, as well as to its future strategies and partners. These symposia were held at venues around the world, and were typically attended by about 1,500 different customers.

**TSMC North America**

Building and maintaining long-term close customer relationships required human interaction. This was done via the TSMC regional offices which were located in the U.S., China, Japan, and Europe. The largest region was North America, which supported more than 70 percent of TSMC’s business. Centered in San Jose, CA, the heart of the Silicon Valley, TSMC North America had about 200 employees acting as account managers, technical marketing experts, and customer service specialists. The regional offices were responsible for direct interaction with customers, identification of potential customers, and sales. They were also the first point of contact for the customer within TSMC. Work in the regional offices was strongly aligned with and closely managed by TSMC headquarters in Taiwan, and frequent travel to Taiwan was an integral part of the job. Account managers were required to complete intense workdays, interacting with customers in the day time, and then coordinating and collaborating with their Taiwanese peers at night, when the workday in Taiwan began.

**VentureTech Alliance**

In 2001, supporting the value chain extension strategy, TSMC created its fully owned venture fund called VentureTech Alliance, headed by Ron Norris, TSMC’s retiring senior vice president of Worldwide Marketing. VentureTech was to invest in companies that would have potential long-term synergy with TSMC’s strengths, assets, and values. Its specific mission was to fuel innovation and growth of fabless design houses, and to support TSMC’s internal strategic

\(^{14}\) Radio Frequency Identification (RFID) is an analog-to-digital conversion technology that uses radio frequency waves to transfer data between a moveable item and a reader to identify, track or locate that item.
Taiwan Semiconductor Manufacturing Company: The Semiconductor Services Company

initiatives. TSMC recognized that its success depended on the growth of the fabless semiconductor sector rather than IDMs, and was interested in investing in promising fabless design houses. Also, TSMC had internal long-term strategic initiatives; for example, TSMC identified the micro-mirror TV chips market, which was entirely owned by TI, as a desirable market. Through its venture fund, TSMC could fund startups developing products in this area.

The fund was entirely owned by TSMC to ensure full control and confidentiality. However, at the same time, the fund was an independent business entity that had to support itself and to be profitable. Independence was important, so that the fund could freely invest in startups that were potential competitors to TSMC’s existing customers.

The fund was based in the U.S. and consisted of four partners, each with deep expertise and experience in the semiconductor industry. In 2004, the company invested in startups in the U.S. and in Taiwan, and had planned investments in China. The fund’s portfolio included early stage fabless, EDA, and IP companies, as well as companies developing products for emerging markets with complex manufacturing needs.

COMPETITION

United Microelectronics Corp. (UMC)

UMC was established in Taiwan in 1980. It was the first private semiconductor company in the country, and the first occupant of the HSIP. UMC was the outcome of the joint ITRI and RCA project that started in 1975 and created a pilot semiconductor manufacturing plant, with all of its related technology, in Taiwan. Since its inception, UMC had been an IDM, designing and producing consumer products such as calculators, watches, and toys. In some cases, the company offered IC foundry services to sell off its extra capacity. In 1995, several of its product lines were flounderings while the foundry market was booming, and UMC decided to become a dedicated IC foundry company. At the time, IC foundry accounted for only 30 percent of UMC’s revenues. That same year, UMC entered into three joint ventures with some well-known IC design houses in the U.S. to establish three dedicated IC foundry companies in Taiwan. Through the joint ventures, UMC could assure orders from the design houses, and share the risk of establishing the fabs.

Following the lead of TSMC, UMC rapidly grew to become the second largest pure foundry in the world with $2.5 billion revenues, about 24 percent revenue market share, capacity of over 220,000 wafers per month, and about 9,000 employees in 2003. UMC typically did less business with IDMs than TSMC, roughly 10 percent. Their product mix was about 60 percent in the computer market, 20 to 25 percent in communications, and 15 to 20 percent in consumer electronics.

15 IC insights, and UMC annual reports.
China’s Semiconductor Industry Gaining Strength

The Chinese semiconductor market was experiencing the fastest growth in the world, registering a CAGR of 46 percent from 2001 to 2004 (compared with CAGR of 11 percent in the Americas). In 2004, the market reached $31 billion. Local consumption was forecast to increase 11 percent in 2005, to a total of $34.3 billion, making China the world’s largest semiconductor market and representing 20 percent of the total demand (see Exhibit 15).

In 2004, more than 90 percent of China’s chip demand was met by foreign makers. However, the government’s goal was to raise the country’s self-sufficiency to above 50 percent. To do that the Chinese government designated the semiconductor industry as one of China’s pillars of economic growth, preparing the way for unprecedented development from virtually nothing in the early 1990s, to Chinese fabs holding about 9 percent of the foundry market’s capacity by the end of 2003.17 This growth was expected to continue with Chinese fabs becoming a dominant player in the semiconductor manufacturing world.

China’s path to becoming dominant in the semiconductor market was much like the path taken in Japan, Korea, and Taiwan. Those countries began by manufacturing low cost consumer products for U.S. companies that wanted manufacturing cost advantages. This foothold into manufacturing enabled companies to define and evolve technologies for components, materials, and equipment. In 2004, China was already the largest producer of TVs, recorders, telephones, calculators, refrigerators, and air conditioners, and the third largest computer producer. It had also been obtaining advanced technology at a rapid pace. In the ten years leading to 2004, China went from being five generations behind in IC processing, to being current with the state-of-the-art capabilities.

In addition to investing heavily in the industry and owning majority stakes in several semiconductor companies, the Chinese government offered tax incentives to outside semiconductor investments. Chipmakers paid no income tax in the first five years of investment and then paid half of the regular tax in the next five years. This led to a standard income tax rate of 15 percent, well below that of many developed countries, including Taiwan’s 25 percent. These tax incentives, along with lower land and labor costs, gave Chinese companies a cost advantage. It was estimated that manufacturing in China could be about 10 percent cheaper than anywhere else18

China’s foundry production revenues reached $771 million in 2003, up 188 percent from $354 million in 2002. This revenue was anticipated to grow strongly, reaching $4.1 billion by 2008, and registering a robust CAGR of 39.6 percent as estimated by Gartner/Dataquest. Eleven large companies were responsible for most of the production, including several pure foundries based on models similar to TSMC and UMC. These eleven companies included Semiconductor Manufacturing International Corp. (SMIC)—the largest Chinese foundry, Advanced Semiconductor Manufacturing Corp. of Shanghai (ASMC), China Huajing Electronics Group Corp., Motorola Tianjin fab, Shanghai Hua Hong NEC Electronics Co. (HHNEC), among others.

18 Andrew Lu, Citigroup Smith Barney.
LOOKING AHEAD

In September 2003, Chang alarmed the semiconductor industry when he said there would be an industry wide recession in 2005 and that the Chinese chipmakers would cause it. In 2004, industrialists and analysts predicted that if the development in China continued as planned, the volume would be enough to cause a serious glut that would drive down prices, slash profit margins, and suppress return on equity. Moreover, some industry observers predicted that China-based foundries would erode the pricing power of Taiwan’s foundries. In fact, as of 2004, China foundries sold products at about 20 to 30 percent less than the industry as a whole, and 40 to 50 percent less than TSMC\(^{19}\). Balancing these predictions were more conservative analysts who pointed to the fact that many of the announced investment plans in China did not materialize. These analysts suggested that the lack of local fabless and design companies was retarding the industry’s development. In addition, foreign fabless companies were worried about the country’s lack of respect to intellectual property.

In December 2004, after the peak of yet another industry up cycle, Chang and his colleagues at TSMC were closely following global and industry developments. In the past, they had been very successful in refining the company’s strategy to adjust to the marketplace. Their track record showed that, not only had they been successful in creating the multi-billion dollar pure-play foundry business, but they had managed to successfully position TSMC as its leader. It was only a few months after TSMC had started production in its newest fab in Shanghai, China, and company executives were reassured that the costs of operating in China were comparable to TSMC’s costs of operating in Taiwan, where they had managed to achieve a high level of efficiency, in particular, with their supply chain partners. They were confident that TSMC’s strategy of maintaining manufacturing excellence, technology leadership, and focusing on customer service, combined with restrained capacity expansion, was the best strategy for the company—strategy that would facilitate continued growth and would help TSMC become its customers’ preferred long term business partner.

\(^{19}\) Macabe Keliher, “*China set to flood the world with Chips*”, Asia Times, February 3, 2004.
Exhibit 1
Worldwide Semiconductor Revenue Growth Rates, 1978-2004

Source: Compiled from “Taiwan Semiconductor Manufacturing Company”, HBS N9-700-090, and IC Insights.

Exhibit 2

Exhibit 3
Cost of Building a Fab, 1983-2003

![Graph showing the cost of building a fab from 1983 to 2003. The cost increases significantly over time.]


Exhibit 4
Top Ten Semiconductor Ranking

<table>
<thead>
<tr>
<th>Rank</th>
<th>Company</th>
<th>Headquarters</th>
<th>2003 Sales (SM)</th>
<th>2004 Forecast (SM)</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2003</td>
<td>2004 (Fcst)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Intel</td>
<td>US</td>
<td>27,030</td>
<td>30,050</td>
<td>11%</td>
</tr>
<tr>
<td>2</td>
<td>Samsung</td>
<td>South Korea</td>
<td>10,400</td>
<td>15,930</td>
<td>53%</td>
</tr>
<tr>
<td>3</td>
<td>Texas Instruments</td>
<td>US</td>
<td>8,250</td>
<td>10,885</td>
<td>32%</td>
</tr>
<tr>
<td>4</td>
<td>Renesas</td>
<td>Japan</td>
<td>7,970</td>
<td>9,475</td>
<td>19%</td>
</tr>
<tr>
<td>5</td>
<td>Infineon</td>
<td>Europe</td>
<td>6,925</td>
<td>9,365</td>
<td>35%</td>
</tr>
<tr>
<td>6</td>
<td>Toshiba</td>
<td>Japan</td>
<td>7,355</td>
<td>9,030</td>
<td>23%</td>
</tr>
<tr>
<td>7</td>
<td>STMicroelectronics</td>
<td>Europe</td>
<td>7,170</td>
<td>8,715</td>
<td>22%</td>
</tr>
<tr>
<td>8</td>
<td>TSMC</td>
<td>Taiwan</td>
<td>5,855</td>
<td>7,665</td>
<td>31%</td>
</tr>
<tr>
<td>9</td>
<td>NEC</td>
<td>Japan</td>
<td>5,605</td>
<td>6,660</td>
<td>19%</td>
</tr>
<tr>
<td>10</td>
<td>Freescale</td>
<td>US</td>
<td>4,630</td>
<td>5,650</td>
<td>22%</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td></td>
<td><strong>91,190</strong></td>
<td><strong>113,435</strong></td>
<td><strong>24%</strong></td>
</tr>
</tbody>
</table>

### Exhibit 5
#### Foundry Growth

<table>
<thead>
<tr>
<th>Year</th>
<th>1993</th>
<th>1995</th>
<th>1997</th>
<th>1999</th>
<th>2001</th>
<th>2003</th>
<th>2005</th>
<th>2007</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales</td>
<td>$1,000</td>
<td>$1,500</td>
<td>$2,000</td>
<td>$2,500</td>
<td>$3,000</td>
<td>$3,500</td>
<td>$4,000</td>
<td>$4,500</td>
<td>$5,000</td>
</tr>
<tr>
<td>Contribution Rate</td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
<td>25%</td>
<td>30%</td>
<td>35%</td>
<td>40%</td>
<td>45%</td>
<td>50%</td>
</tr>
</tbody>
</table>

2002-2010 CAGR
WW IC = 9%
Foundry = 16%

Source: TSMC.

### Exhibit 6
#### Top Ten Pure-Play Foundry Business

<table>
<thead>
<tr>
<th>Rank</th>
<th>Company (Headquarters)</th>
<th>2002 Sales ($M)</th>
<th>% Change</th>
<th>% Total</th>
<th>2003 Sales ($M)</th>
<th>% Change</th>
<th>% Total</th>
<th>2004* Sales ($M)</th>
<th>% Change</th>
<th>% Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TSMC (Taiwan)</td>
<td>4,655</td>
<td>26%</td>
<td>54%</td>
<td>5,855</td>
<td>26%</td>
<td>52%</td>
<td>8,030</td>
<td>37%</td>
<td>47%</td>
</tr>
<tr>
<td>2</td>
<td>UMC Group (Taiwan)</td>
<td>2,154</td>
<td>6%</td>
<td>25%</td>
<td>2,740</td>
<td>27%</td>
<td>24%</td>
<td>4,200</td>
<td>53%</td>
<td>24%</td>
</tr>
<tr>
<td>3</td>
<td>Chartered (Singapore)</td>
<td>485</td>
<td>1%</td>
<td>6%</td>
<td>728</td>
<td>50%</td>
<td>6%</td>
<td>1,215</td>
<td>67%</td>
<td>7%</td>
</tr>
<tr>
<td>4</td>
<td>SMIC (China)</td>
<td>70</td>
<td>N/A</td>
<td>1%</td>
<td>150</td>
<td>50%</td>
<td>6%</td>
<td>255</td>
<td>67%</td>
<td>6%</td>
</tr>
<tr>
<td>5</td>
<td>Dongbu/Anam (S. Korea)</td>
<td>260</td>
<td>23%</td>
<td>3%</td>
<td>330</td>
<td>27%</td>
<td>3%</td>
<td>450</td>
<td>36%</td>
<td>3%</td>
</tr>
<tr>
<td>6</td>
<td>SSMC (Singapore)**</td>
<td>85</td>
<td>89%</td>
<td>1%</td>
<td>155</td>
<td>82%</td>
<td>1%</td>
<td>270</td>
<td>74%</td>
<td>2%</td>
</tr>
<tr>
<td>7</td>
<td>HHNEC (China)</td>
<td>150</td>
<td>N/A</td>
<td>2%</td>
<td>170</td>
<td>13%</td>
<td>2%</td>
<td>255</td>
<td>50%</td>
<td>1%</td>
</tr>
<tr>
<td>8</td>
<td>Jazz (US)</td>
<td>160</td>
<td>7%</td>
<td>2%</td>
<td>185</td>
<td>16%</td>
<td>2%</td>
<td>240</td>
<td>30%</td>
<td>1%</td>
</tr>
<tr>
<td>9</td>
<td>Silterra (Malaysia)</td>
<td>60</td>
<td>100%</td>
<td>1%</td>
<td>82</td>
<td>37%</td>
<td>1%</td>
<td>210</td>
<td>156%</td>
<td>1%</td>
</tr>
<tr>
<td>10</td>
<td>X-Fab (Europe)</td>
<td>100</td>
<td>8%</td>
<td>1%</td>
<td>127</td>
<td>27%</td>
<td>1%</td>
<td>200</td>
<td>57%</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>416</td>
<td>38%</td>
<td>5%</td>
<td>592</td>
<td>42%</td>
<td>5%</td>
<td>1,070</td>
<td>81%</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>8,575</td>
<td>20%</td>
<td>100%</td>
<td>11,330</td>
<td>32%</td>
<td>100%</td>
<td>17,170</td>
<td>52%</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Data for 2004 is forecasted
** Partially owned by TSMC

Exhibit 7
Semiconductor Industry Supply Chain Vertical Disintegration

Exhibit 8
ESRO/ITRI Diagram of the Taiwan IC Industry Supply Chain in the 1990s

Source: TSMC.

## Exhibit 9
Summary of TSMC Financials, 1999-2003

<table>
<thead>
<tr>
<th>Currency used: $NT</th>
<th>Year ended as of December 31,</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1999</td>
</tr>
<tr>
<td><strong>US GAAP</strong></td>
<td></td>
</tr>
<tr>
<td>Net Sales</td>
<td>76,305</td>
</tr>
<tr>
<td>cost of Sales</td>
<td>(52,163)</td>
</tr>
<tr>
<td>Operating Expenses</td>
<td>(12,310)</td>
</tr>
<tr>
<td>Income (loss) from operations</td>
<td>11,832</td>
</tr>
<tr>
<td>Income (loss) before income tax</td>
<td>10,986</td>
</tr>
<tr>
<td>income tax (expense) benefit</td>
<td>2,383</td>
</tr>
<tr>
<td>Net income (loss)</td>
<td>13,884</td>
</tr>
<tr>
<td><strong>Other Financial Data</strong></td>
<td></td>
</tr>
<tr>
<td><strong>ROC GAAP</strong></td>
<td></td>
</tr>
<tr>
<td>Gross margin</td>
<td>41%</td>
</tr>
<tr>
<td>Operating margin</td>
<td>29%</td>
</tr>
<tr>
<td>Net margin</td>
<td>31%</td>
</tr>
<tr>
<td>Capital expenditures</td>
<td>51,459</td>
</tr>
<tr>
<td>Depreciation and amortization</td>
<td>25,198</td>
</tr>
<tr>
<td>Cash provided by operating activities</td>
<td>40,253</td>
</tr>
<tr>
<td>Cash used in investing activities</td>
<td>(60,952)</td>
</tr>
<tr>
<td>Cash provided by (used in) financing activities</td>
<td>39,518</td>
</tr>
<tr>
<td>Net cash flow</td>
<td>18,646</td>
</tr>
<tr>
<td><strong>Operating Data</strong></td>
<td></td>
</tr>
<tr>
<td>Wafers sold (in thousand)</td>
<td>1,826</td>
</tr>
<tr>
<td>Average utilization rate</td>
<td>97%</td>
</tr>
<tr>
<td>Employees</td>
<td>7,455</td>
</tr>
</tbody>
</table>

Note: Parts of the financial statement are prepared and presented in accordance with the Republic of China (‘‘ROC” or Taiwan) GAAP, which differ in some material respects from US GAAP.

Source: TSMC SEC filings.
Exhibit 10
TSMC R&D Investment, 1992-2004

Source: TSMC.

Exhibit 11
TSMC Technology Roadmap, 1997-2009

Source: TSMC.
Exhibit 12
TSMC Information Systems

TSMC IT Architecture

E-Commerce

Customer

- Forecast
- Product Info
- PO

- Order Status
- WIP
- Shipping Info
- Tech Doc
- Eng Info

Employees

- MyTSMC
- eMail
- Workflow Automation

- EKM/ICM
- Knowledge Management

- EDW
- Eng Data Workflow

Business Operations

- ERP
  - Finance/Accounting
  - Material Mgmt
- E-HR
  - HR Admin./Payroll
  - Training

- New Tech Dev/ Deploym't Mgmt
  - Tech Dev.
  - Tech Deployment

Manufacturing IT

- Engineering (Expert sys)
- Manufacturing Planning (eMP)
- TSMC-YES (Yield Enhancement sys)

- TSMC Supply-Direct
  - A/P
  - Order Status

- TSMC Supply-Online

IT Infrastructure

- Data Center Mgt
- Server & Storage Mgt
- Global Data Network
- IT Security
- Desktop & Notebook PC Mgt

Source: TSMC.
Exhibit 13
ESCM Architecture

Source: TSMC.

Exhibit 14
TSMC Sales Trends, 1992-2004

Source: TSMC.
Exhibit 15
Regional IC Markets, 2001-2005